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Delineation of wellhead protection areas in the Umbria region. 2. Validation of the proposed procedure

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Abstract

In the companion paper [1] a procedure has been presented to delineate the wellhead protection areas in the Umbria region, where a large number of minor groundwater resources are exploited. While the national and the regional regulations do not differentiate in the protection area delineation guidelines between large and small resources, the proposed procedure allows increasing the model complexity with the increase in the resource relevance and hence in the degree of knowledge about the aquifer. In this paper the procedure is tested with reference to actual cases and the results of models with different complexity are compared. The importance of the effects of the mean-regional gradient on the delineation of the protection area for small catchments is pointed out.

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Keywords: protection area, well, spring, small resources

1. Introduction

In the Umbria region a large number of small catchments provides drinkable water to a limited number of customers. For these resources, basing on the national and regional regulation requirements discussed in the companion paper [1], managers such as Umbra Acque S.p.A. must delineate the protection areas in order to defend

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the water resources and the health of the customers. At the same time, when minor resources are considered, the used models must face the reduced amount of information available about the aquifers. As a result, in [1] a procedure is presented, where the complexity of the applied techniques increases with the level of knowledge about the groundwater flow parameters. In this paper, the procedure is applied to some case studies and the results of the models are compared to assess their reliability.

2. Procedure verification

To test the procedure, several case studies have been considered. To assess if and when the increase in the model complexity was crucial in the delineation of the protection areas, some tests were carried out on wells where data were available for both simplified and more complex models. In the following the results of some of the considered cases are shown.

2.1. Riosecco well-field

The results for the Riosecco well-field, where the total discharge of 35 l/s is equally drawn from five wells, are shown in the following. Due to some pumping tests and geological inspections carried out by the manager, the estimated values of transmissivity (0.007 m^2/s), porosity (0.2) and aquifer thickness (30 m) were available for the aquifer. Furthermore, the water level was observed in 21 boreholes close to the well-field.

In Fig. 1 the well positions are shown along with the absolute protection areas (cyan lines) and the protection area (blue) defined by means of the simple geometric criterion. Basing on the outlined procedure, the wells cannot be considered as singles, since their protection areas overlap. As a consequence, the fixed radius and the simplified analytical models have not been applied.

To delineate the isochrones corresponding to 180 d, several scenarios and models are considered. As a first step, the Tiber River is considered as a constant head boundary in both a finite difference and an analytical element model, MODFLOW [3] and WhAEM [4] respectively. The use of the analytical element model has shown to be much simpler, providing the same results in terms of flow field and piezometric head distribution of the finite difference model when in the latter the boundaries are properly defined or very far from the area of interest. In a first simulation the computed and observed heads at the available boreholes, used as piezometers, were compared, considering the effects of the Tiber River and the drawing wells. The delineated isochrones for t =180 d are the orange lines in Fig. 1 while the calculated values at the boreholes are compared with the observed ones in Fig. 2 for both the finite difference (MN) and the analytical element (WN) models. This figure clearly shows that both the models are very poor in the groundwater flow prediction, with almost coincident results. As a matter of fact, the undisturbed groundwater flow in the area is mainly orthogonal to the Tiber River and unless this effect is modeled, the simulations do not provide good results (Fig. 3a).

In Fig. 3b the results of another simulation are shown, where a mean gradient is introduced to take into account the actual undisturbed groundwater flow. The water table gradient value, i, and its direction with respect to north, α, were estimated by fitting the observed data with a plane. Both finite difference and analytical element models were used, providing to the finite difference model the proper boundary conditions. The comparison of Fig. 3a and b clearly shows the effects of the regional flow on the flow field while the comparison of the orange and the green lines in Fig. 1 shows the effects in terms of protection areas. Fig. 2 shows the improvements in the goodness of fit of the calculated data to the observed data for both the finite difference (MB) and analytical element (WM) models when the regional flow is considered. The relatives trajectories that have been used to evaluate the protection areas when the regional flow is considered (green lines) or not (orange lines) are shown in Fig.4. Although an A type resource is considered [1], with a drawn discharge greater than 30 l/s, the effect of the regional flow in delineating the protection area is visible. Since a decrease in the well drawing can only enhances this effect, reducing the perturbation induced by the well in the undisturbed flow, the conclusion is that the regional flow definition is crucial for the delineation of the protection area for the C type, or local, resources.

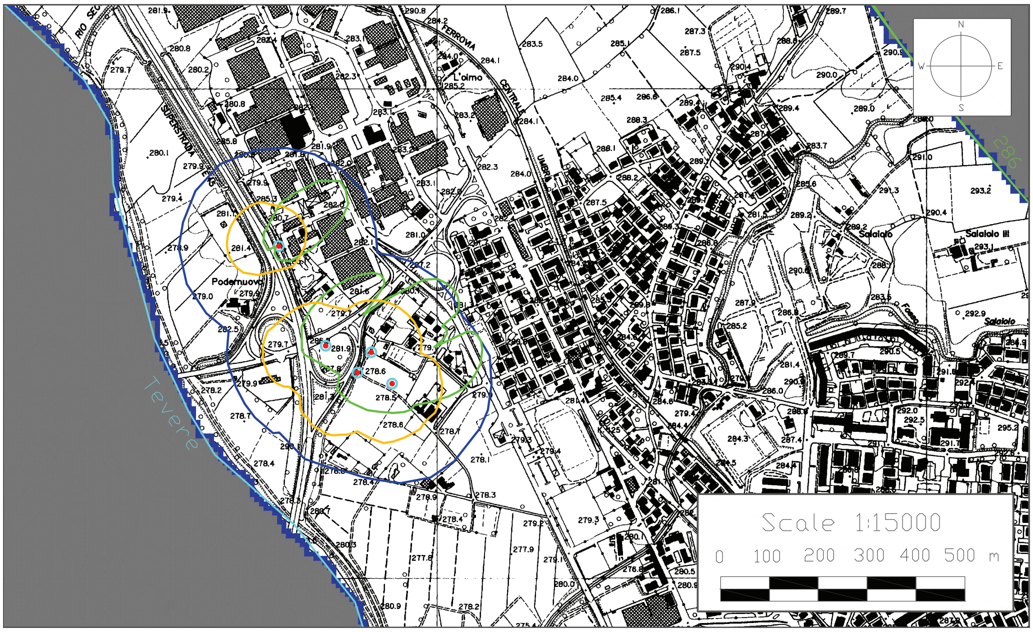

Fig. 1. Riosecco wells (red circles): the absolute protection areas (cyan lines), and the protection area defined by means of MODFLOW and WhAEM considering (green) and not considering (orange) the regional flow; the protection area defined by the geometric criterion, i.e. circles with 2000m radius (bleu) are also shown for reference.

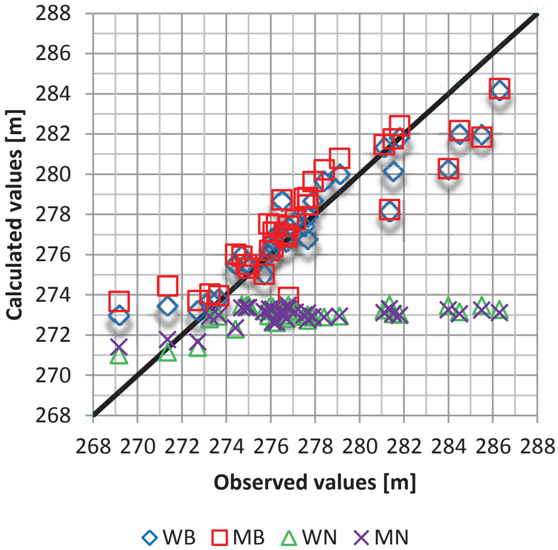

Fig. 2. Calculated vs. observed values at the boreholes obtained by MODFLOW (M) and the WhAEM (W) models, considering (B) and not considering (N) the regional flow.

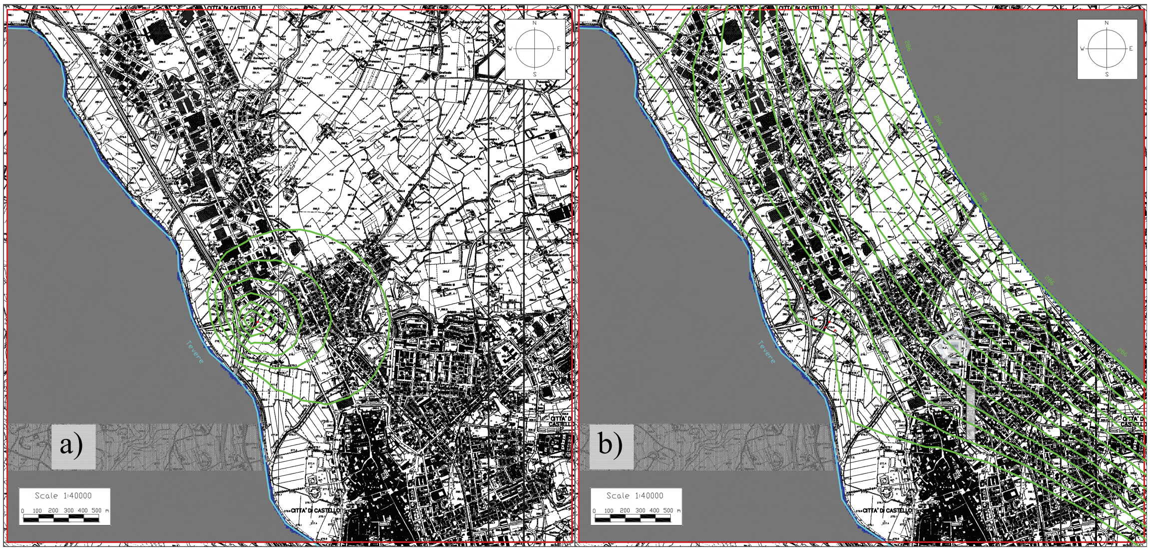

Fig. 3. Isopiezic lines obtained by MODFLOW when the regional flow (a) is not considered or (b) is considered by means of a proper boundary condition.

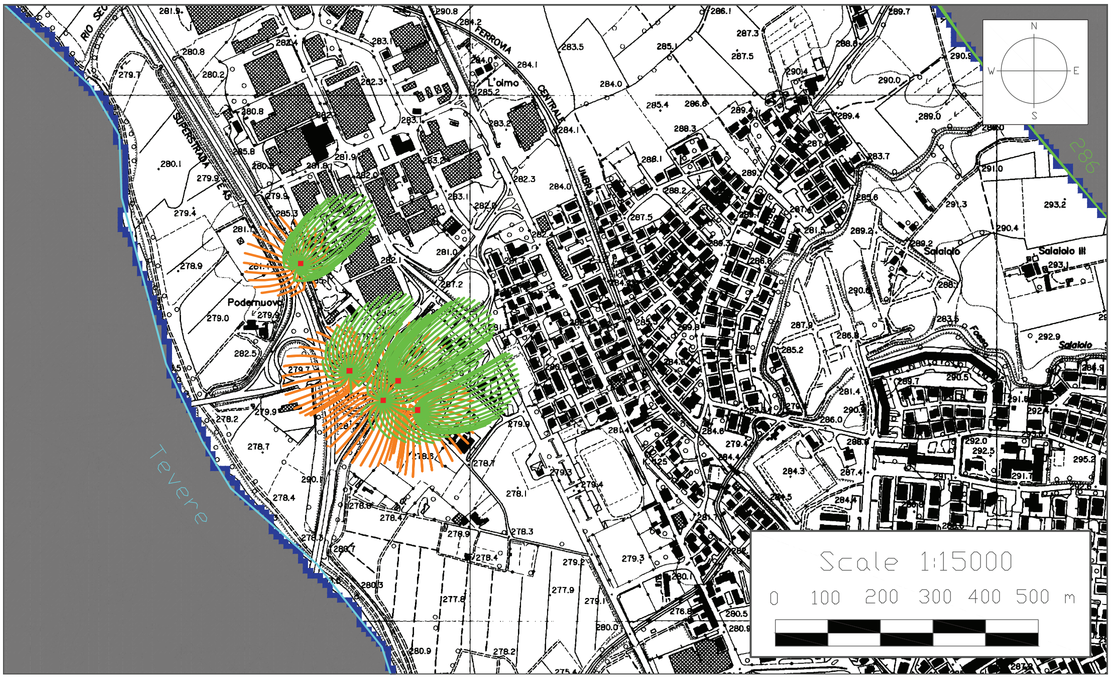

Fig. 4. Trajectories used to evaluate the isochrones for t=180d and the protection areas of Fig. 1 when the regional flow is considered (green lines) or not (orange).

2.2. Nese well

One of the other tests concerned the Nese well, where a discharge of 18 l/s is drawn from a confined aquifer. Due to some pumping tests and geological studies previously carried out, the estimated values of transmissivity (0.014 m^2/s), porosity (0.2) and aquifer thickness (20 m) were available for the aquifer.

Fig. 5 shows the well location (red circle) close to the Tiber River (cyan line) and the Nese Creek. Basing on the information provided about the geological stratigraphy, it was possible to mark out an area where the estimated transmissivity is about 0.005 m^2/s. Furthermore, five wells in the surrounding areas used as piezometers allowed to estimate a regional flow with a slope i_E = 1.30 % and an angle α_E = 7.9° with respect to the East direction.

Fig. 6 shows the 180 d protection areas delineated considering (magenta line) or not (green) the area with the lower transmissivity.

To assess the effect of the sensitivity of the regional slope on the protection areas delineation [4], both the slope i_E and the angle α_E have been varied. Basing on previous studies, the "20-20" rule has been used, varying the slope of ±20% of its value and the angle of ±20°. As a result, the limiting values of i_{Emin} = 1.04%, i_{Emax} = 1.56%, α_{Emin} = −12.1°, α_{Emax} = 27.9° are derived and then four different simulations have been considered and shown in Fig. 7, with i_{Emax} and α_{Emin} (magenta lines in Fig. 7), i_{Emin} and α_{Emin} (yellow), i_{Emin} and α_{Emax} (bleu), i_{Emax} and α_{Emax} (green). In Fig. 8 the convex hull comprehending all the four protection areas (green line) is compared with the protection area obtained with i_E and α_E (magenta line).

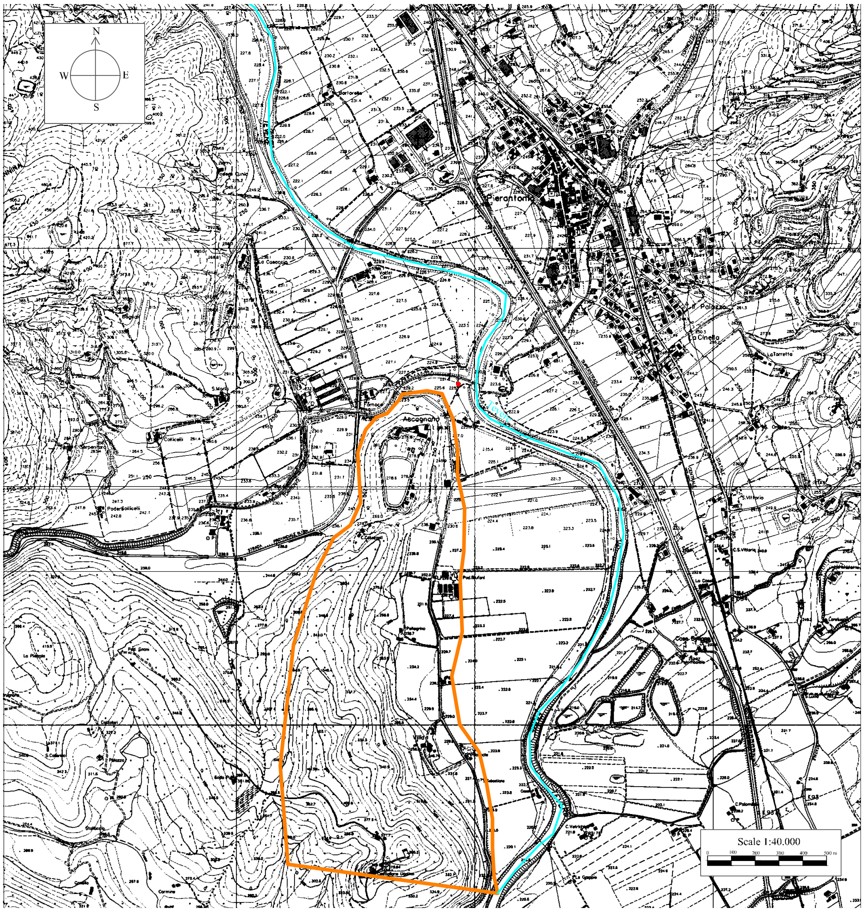

Fig. 5. The Nese well (red circle) close to the Tiber River (cyan line) and the Nese Creek: the orange line denotes a discontinuity in the transmissivity value.

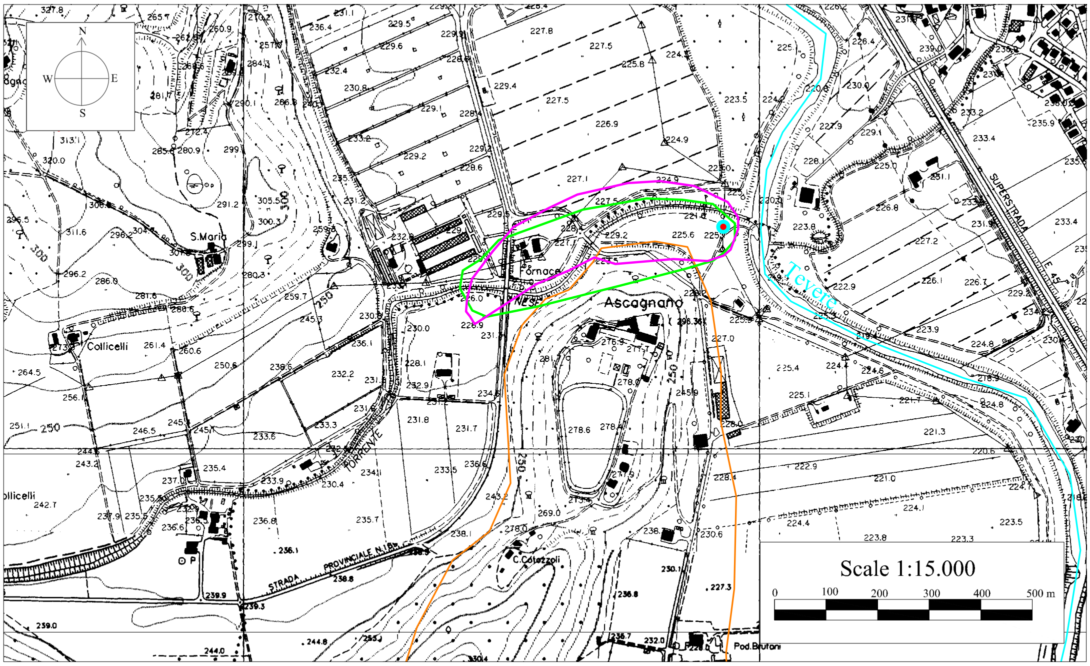

Fig. 6. Protection areas of the Nese well delineated considering (magenta line) or not (green) the area with the lower transmissivity (inside the orange line).

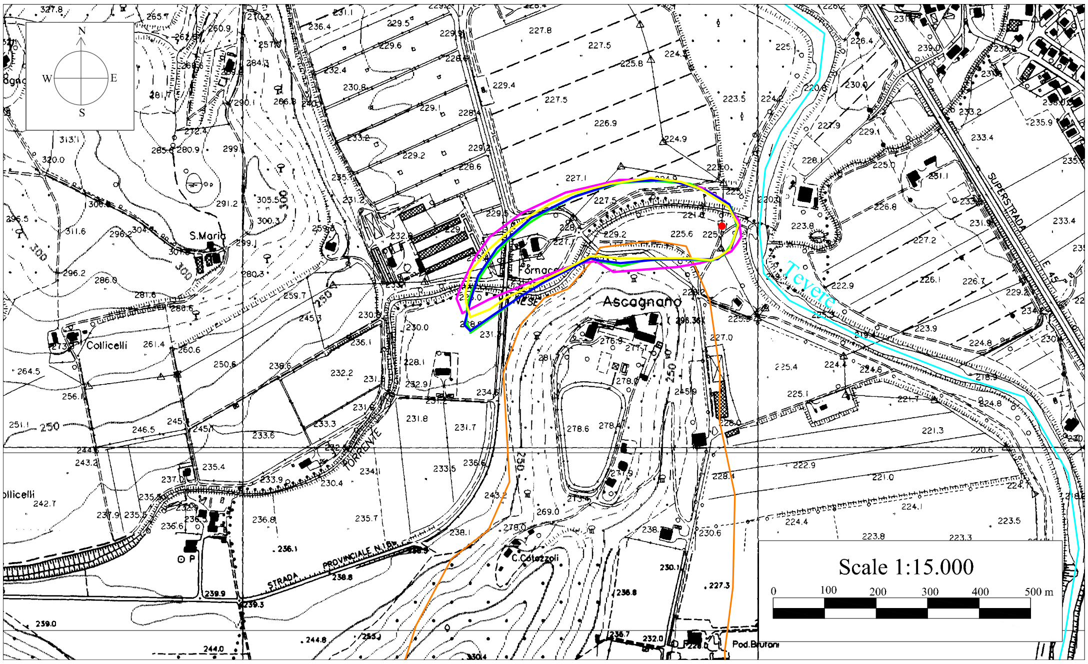

Fig. 7. Nese protection areas with i_{Emax} and α_{Emin} (magenta lines), i_{Emin} and α_{Emin} (yellow), i_{Emin} and α_{Emax} (bleu), i_{Emax} and α_{Emax} (green).

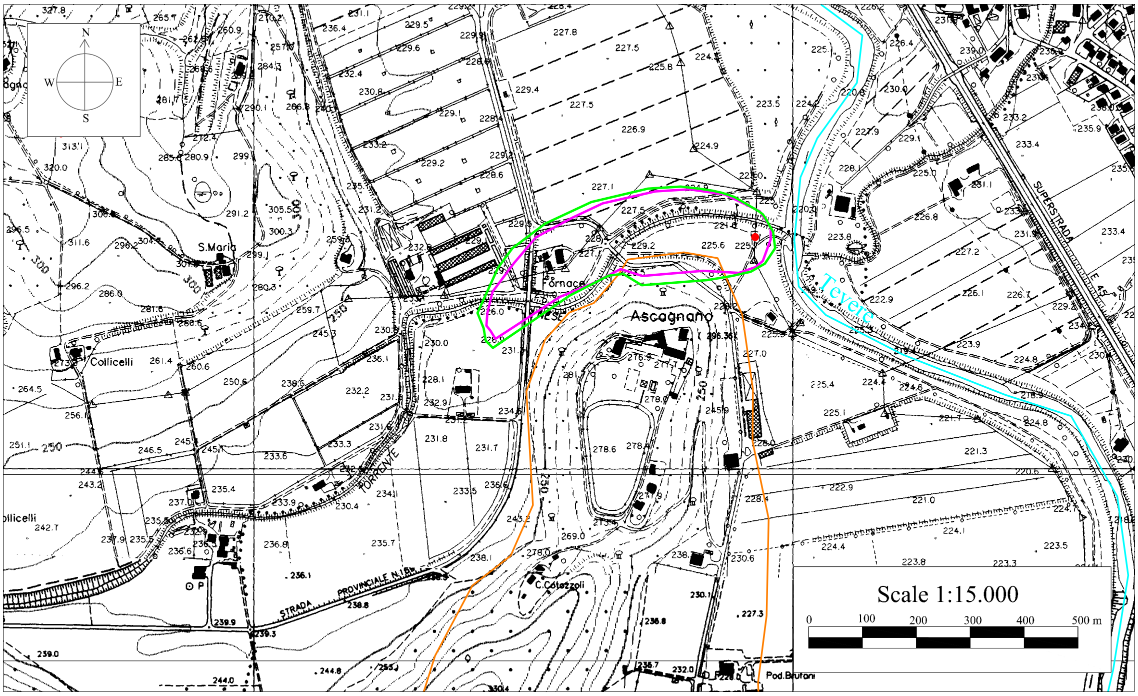

Fig. 8. The convex hull comprehending all the protection areas obtained considering the variations in i_E and α_E in Fig. 6 (green line) is compared with the protection area obtained with the mean values of i_E and α_E (magenta line)

3. Conclusions

The systematic application in the part of the Umbria Region managed by Umbra Acque S.p.A. of a procedure for the delineation of the protection areas allows some main remarks.

Since most of the exploited resources provide low discharges to a reduced number of customers, the effects of the regional flow on the flow field prevail or are comparable with respect to the disturbance induced by the drainage. As a result, where other wells or springs in the surrounding area can provide information about the regional flow, the improvement in the protection area delineation reliability are sensible. Furthermore, the uncertainty in the regional flow direction and magnitude can seriously affect the reliability of the protection area definition.

The lack of a study at the regional scale, embedding all the available information provided by hydrologic and geologic studies as well as piezometric observations, does not allow a reasonable definition of the regional flow and of its uncertainty. This study could also provide a stochastic characterization of other parameters such as the hydraulic conductivity to take into account the effects of the uncertainties.

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